PHYSICS 222, Fall 1996
Exam #3
Thursday, November 21, 1996, 8:00 – 9:30 pm
VERSION A

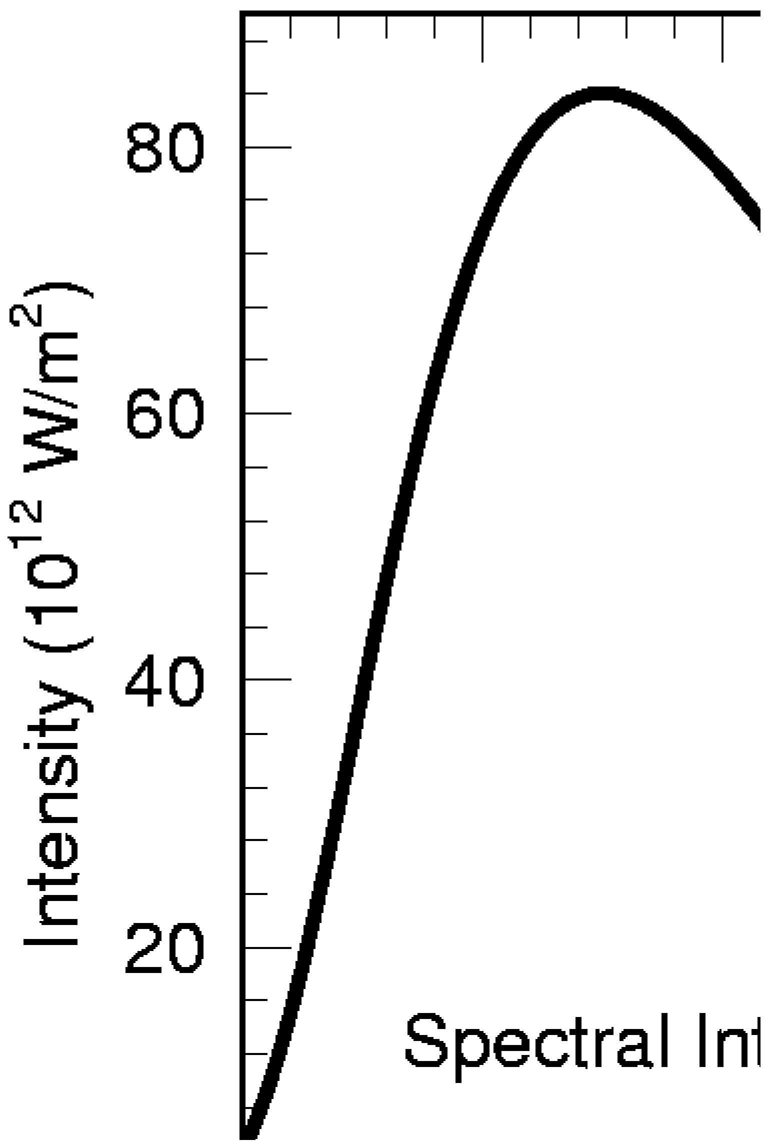
Answers and Solutions

27. The **wave character of the electron** can be proven

 (A) with Millikan's experiment (e=1.602×10^{-19} C),
 (B) with Rutherford's experiment (discovery of the atomic nucleus),
 (C) with the photoelectric effect,
 (D) with Compton scattering between x-rays and electrons,
 (E) **with a proper type of Young's single-slit experiment**.

28. The spectral intensity of our Sun is shown in the Figure. In about 5 billion years, the sun will blow up and become a giant star. In this process, the surface temperature of the Sun decreases by about a factor of 2. In 5 billion years, the intensity maximum in the Sun's spectrum will occur at

 (A) **1000 nm.**
 (B) 500 nm.
 (C) 750 nm.
 (D) 250 nm.
 (E) 2000 nm.



29. In geometric optics, light is modeled by ray
following is **NOT** described by this model?

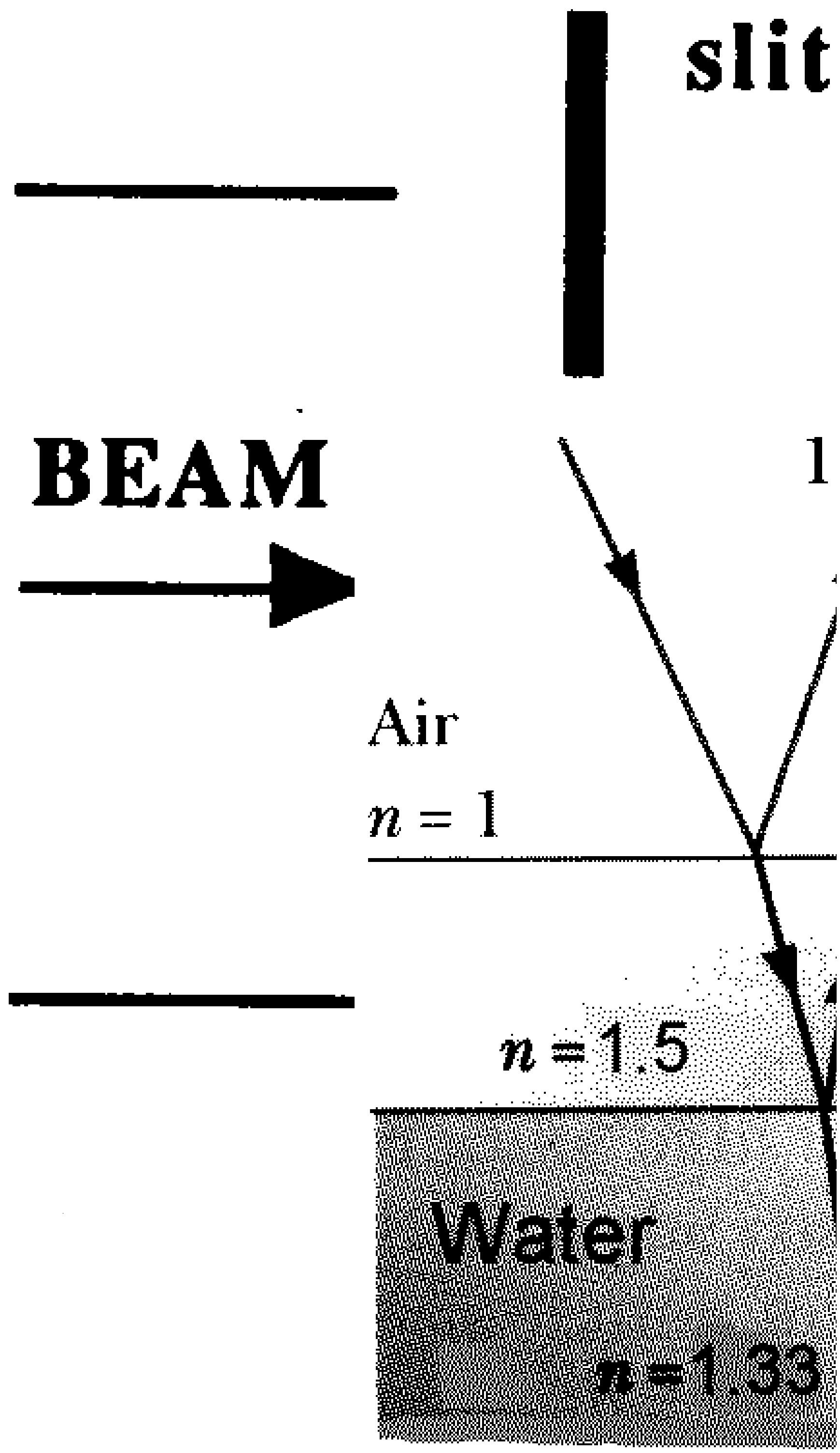
 (A) Snell's law of refraction.
 (B) **Double-slit experiment with narro**
 (C) Angle of incidence equals angle of reflec
 (D) Total internal reflection.
 (E) Light passing through a wide slit (many

30. Polarization experiments provide evidence th

 (A) a longitudinal wave,
 (B) a stream of photons,
 (C) **a transverse wave,**
 (D) nearly monochromatic,
 (E) some type of wave.

31. Two narrow slits in a plane surface are separated by a distance of 0.250 mm. They are illuminated with a coherent beam of monochromatic red light with wavelength 690 nm. The resulting interference pattern falls on a screen located 750 mm away as shown in the Figure. Calculate the distance between the second minimum on one side of center and the second minimum on the othe

(A) 1.0 mm.
(B) **6.2 mm.**
(C) 3.1 mm.
(D) 2.0 mm.
(E) None of the above.



32. A piece of glass 0.600 The glass is illuminat following wavelengths

(A) 456 nm.
(B) 482 nm.
(C) **720 nm.**
(D) 546 nm.
(E) 578 nm.

33. In modern physics, li of the photons has ar **WITHOUT** requirin

(A) Emission and ab
(B) Scattering of ligh
(C) **Diffraction of**
(D) Wavelength spec
(E) Electrons in a m

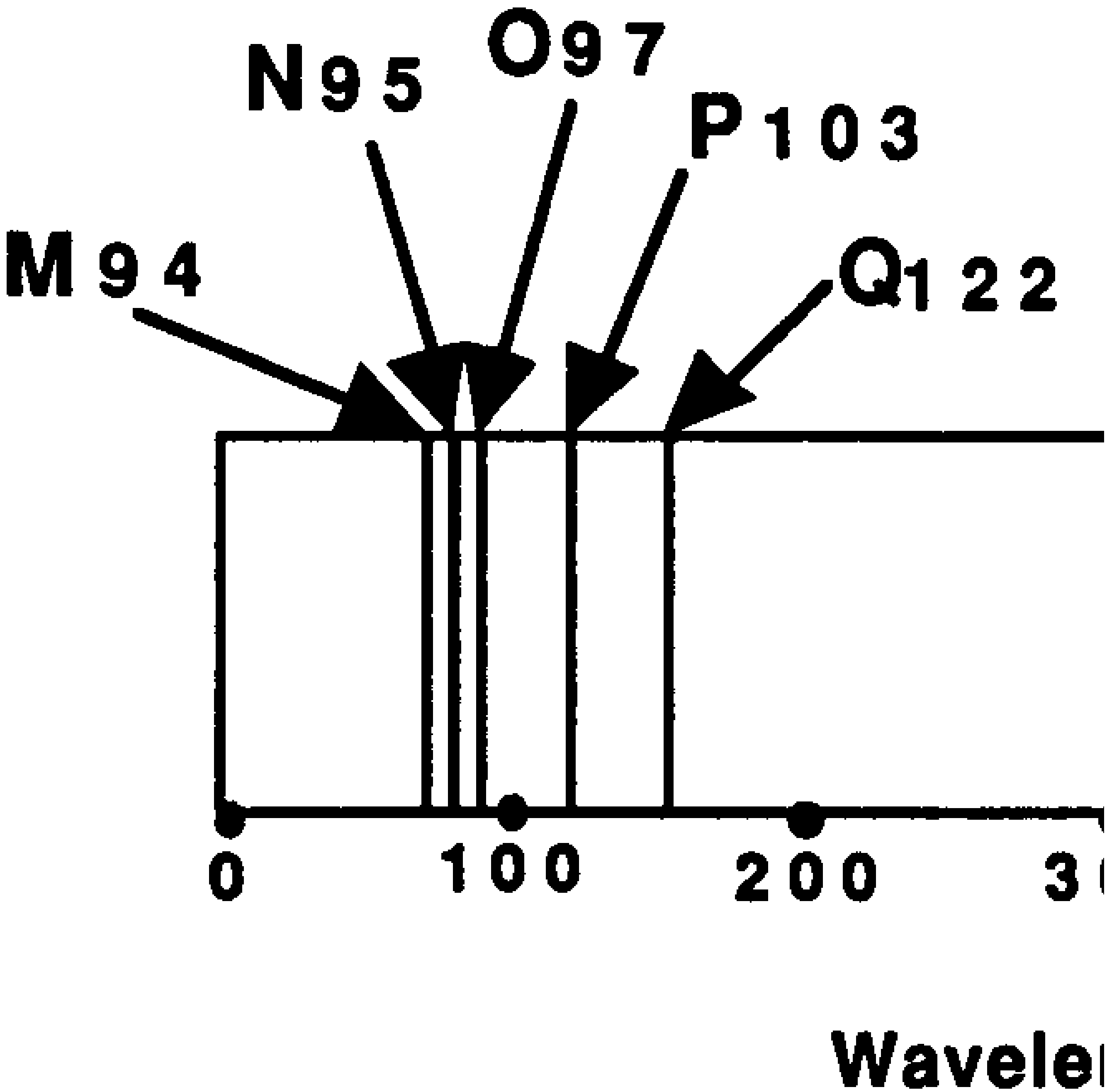
34. In Bohr's model of tl about the nucleus (a s that the radius for the the fourth shell (coun

(A) 0.212 nm.
(B) 0.476 nm.
(C) **0.846 nm.**
(D) 0.529 nm.
(E) 0.013 nm.

35. An interstellar gas cloud consists of hydrogen. The emperor of the universe has recently ruled that the highest excited energy state which any hydrogen atom may have is the n=3 state (part of his Freedom to Restrain Excitation Act). White light from a star passes through the cloud on its way to earth. Which wavelengths will be absorbed or emitted by this cloud? (The white star light covers all wavelenghts from 50 nm to 1000 nm).

36.

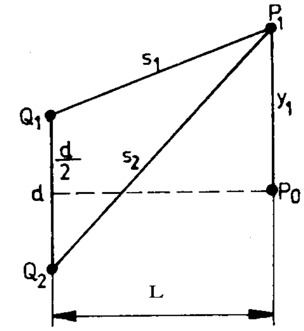
37.



38.

(B) **0.1875 cm^3.**
(C) 0.0225 cm^3.
(D) 0.00125 cm^3.
(E) 0.0625 cm^3.

Problem 1: Diffraction and Interference of EM waves



Two radio transmitters Q_1 and Q_2 driven by the same source are separated by a distance d=2.50 m, as shown in the Figure. Both transmitters generate a sinusoidal spherical electromagnetic wave. The receiver antenna senses an intensity maximum at P_0. As it is moved from P_0 to P_1, the intensity decreases steadily and reaches a minimum at P_1. The distance between the lines Q_1Q_2 and P_0P_1 is L=3.5 m. The distance from P_0 to P_1 is y_1=1.55 m.

A. Why does the receiver find a maximum radio wave intensity at point P_0? (2 points). What is the condition for the path difference $|s_1 - s_2|$ to generate an intensity minimum at P_1? (2 points).

Answer: The path difference between Q_1 and P_0 and Q_2 and P_0 vanishes. Therefore, both waves arrive in phase at P_0. Therefore, they interfere constructively and generate an intensity maximum. At P_1, the path difference $|s_1 - s_2|$ needs to be equal to half a wavelength (or an odd multiple thereof). This will create a minimum at P_1.

B. What are the wavelength and the frequency of the radio wave? (4 points). *Hint:* Do not use the small-angle approximation. Instead, use Pythogoras's Theorem.

Answer: First, calculate the path difference $|s_1 - s_2|$:

$$s_1 = \sqrt{l^2 + (y_1 - d/2)^2} = 3.51 \text{ m.} \quad (1)$$

$$s_1 = \sqrt{l^2 + (y_1 + d/2)^2} = 4.48 \text{ m.} \quad (2)$$

$$|s_1 - s_2| = 0.97 \text{ m.} \quad (3)$$

Since the path difference is equal to half a wavelength for the first minimum, the wavelength is 1.94 m. This corresponds to a frequency of 155 MHz.

C. A **single slit** with a width of 0.01 mm is illuminated with light from a sodium lamp containing two wavelengths λ_1=589.00 nm and λ_2=589.59 nm. The resulting diffraction pattern is displayed at a screen, whose separation from the slit is L=3.5 m. What is the separation between the **zero-order maximum** observed for λ_1 and the **zero-order maximum** observed for λ_2 (3 points)? Explain your answer in complete sentences.

Answer: The zero-order maximum occurs at θ=0° for any wavelength. Therefore, the separation between the zero-order maxima is 0 m.

D. In the same single-slit arrangement, what is the separation between the **first-order minimum** observed for λ_1 and the **first-order minimum** observed for λ_2 (5 points)?

Answer: The first-order minimum occurs at $\theta \sim \sin\theta = \lambda/a$,
therefore $\Delta\theta = \theta_1 - \theta_2 = |\lambda_1 - \lambda_2|/a = 59\times10^{-6}$ rad.
The two minima are separated by $\Delta y = L\Delta\theta = 0.2$ mm.

Problem 2: Photoelectric Effect and Compton Scattering

A. List **three** experimental results from the **photoelectric effect**, which cannot be explained using the classical (Maxwell) theory for electromagnetic waves. Use complete sentences, no equations (3 points).

Answer:
- No photoelectrons are emitted, if the frequency of the incident light falls below the cutoff frequency (even if the intensity is very high).
- The maximum kinetic energy of the photoelectrons (or the stopping potential) is independent of the light intensity.
- The maximum kinetic energy of the photoelectrons (or the stopping potential) increases with increasing light frequency (or decreasing wavelength).
- Electrons are emitted from the surface almost instantaneously, even at low light intensities.

B. Which equation did Einstein propose to explain these observed results? (1 point) Describe in complete sentences how Einstein's theory can be used to explain the three experimental results you listed in part A. (3 points).

Answer:
- **Einstein's Equation:** $K_{\text{max}} = hf - \Phi$.
- The energy of the photon needs to be larger than the work function. Otherwise, no electron can be emitted. This explains the cutoff frequency.
- The maximum kinetic energy of the photoelectron only depends on the energy of the photoelectron and the work function, but not on light intensity. The light intensity only affects the number of photons (and therefore the number of emitted electrons), but not their kinetic energy.
- The maximum kinetic energy of the photoelectron is equal to the photon energy minus the work function.
- Each photon creates one photoelectron, if its energy is larger than the work function. Since this is a particle-particle collision, the onset is very fast and does not depend on the light intensity.

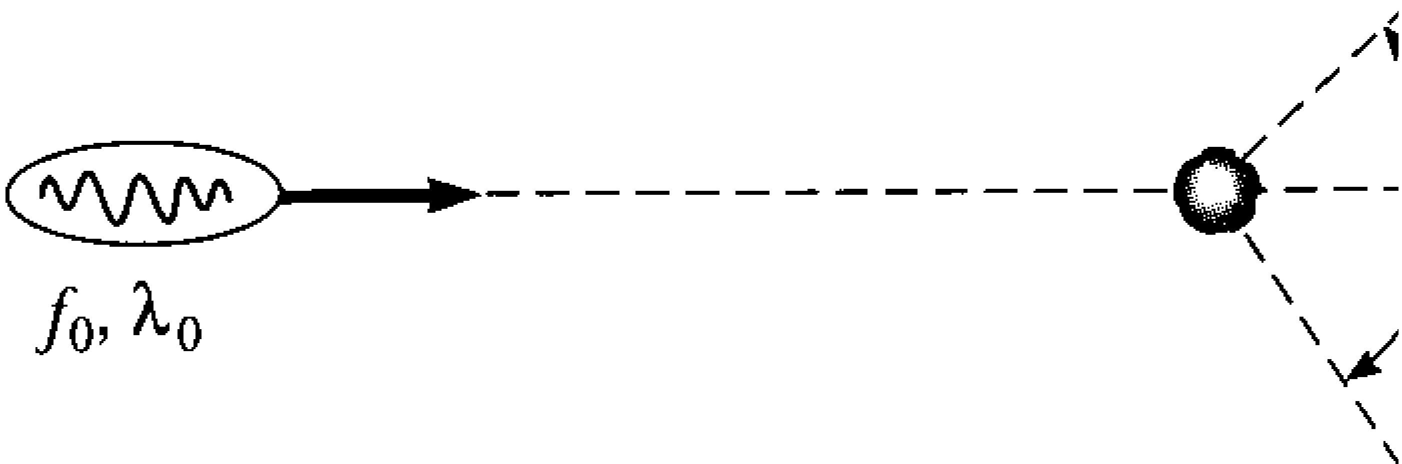
C. A sodium surface is illuminated with light of wavelength 300 nm. The maximum kinetic energy of the ejected photoelectrons is 1.68 eV. The cutoff wavelength is 505 nm. Find the work function for sodium metal (3 points).

Answer: The work function is $\phi = hc/\lambda_c$=2.46 eV.

D. X-rays of wavelength λ_0=0.200 nm are scattered from a block of material. The scattered x-rays are observed at an angle of θ=90° to the incident beam (see Figure). Calculate the **velocity of the recoiling electron** (4 points).

Answer: The wavelength change is $\Delta\lambda = \lambda_{\text{Compton}}(1-\cos\theta) = \lambda_{\text{Compton}} = h/mc$=0.002 nm. Therefore, the wavelength of the scattered x-rays is λ'=0.202 nm. The energy of the incident x-rays is hc/λ_0=6199 eV, that of the scattered x-rays is hc/λ'=6125 eV. The energy difference of 74 eV is the kinetic energy of the recoiling electron. Its velocity is $v = \sqrt{2K/m}$=5.1×10^6 m/s.

Ans



(b) Quantum model

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